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Hypatia: A Comprehensive Energy System Modeling Framework

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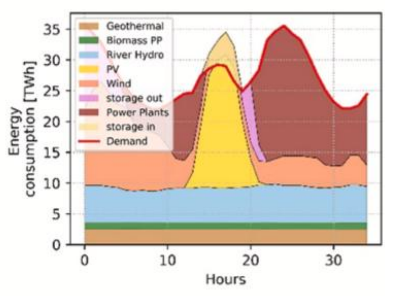
Abstract

Hypatia is an energy system modeling framework built in Python, aiming to address the complex challenges associated with optimizing operational dispatchability and long-term planning aspects of energy systems. This framework provides an advanced tool for decision-makers and researchers to explore different policy-driven scenarios for energy transitions, utilizing multi-objective optimization or near-optimal solutions to explore the entire spectrum of solutions based on optimizing net present cost or emissions. With its open-source nature, Hypatia offers a customizable solution for analyzing diverse energy transition possibilities, making it highly valuable for those interested in analyzing and shaping the future of energy systems.

Keywords: energy system analysis, long-term energy planning, energy system dispatchability, multi-objective optimization, two stage optimization, modelling to generate alternatives

Inputs

Existing energy mix



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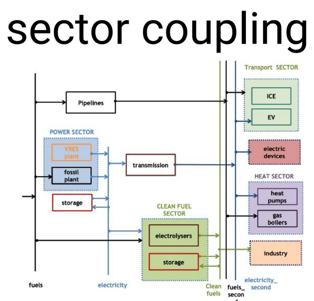
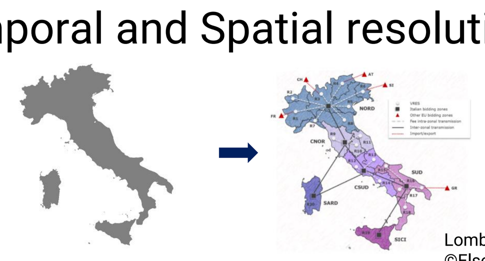
Techno-economic detail and sector coupling



Temporal and Spatial resolution



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Excel-based structural inputs:

- Time horizon
- Regions
- Technologies
- Carriers

The structural inputs allow to automatically generate the parameters input file

Excel-based parameters:

- Technological characterisation
- Economics for each technology
- Environmental data
- Scenario and policy-based data

Operation and Planning Energy System Modelling Framework written in Python

LEAST COST OPTIMIZATION

$$OBJ = \sum_{reg}\sum_{tech}\sum_{year} Total\ Discounted\ System\ Cost$$

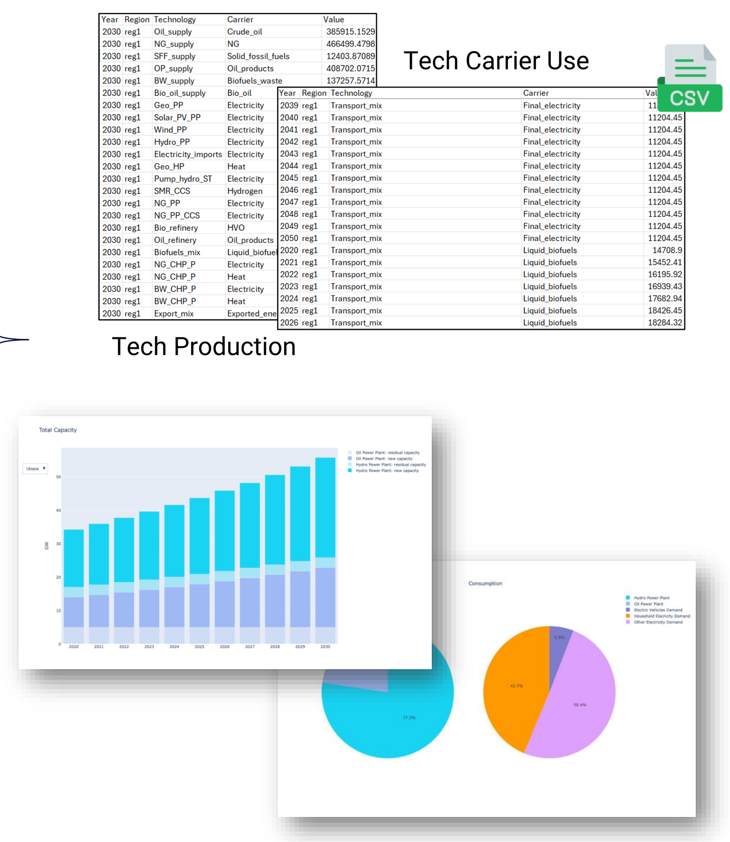
Energy system modelling for short & long-term horizon with a multi node approach (localized for demand & supply) which includes traded carriers and cross border linkages and Sector-coupling

Subject to:

- Energy constraints
- Economic constraints
- Technological constraints

Results

Plots and **Spreadsheets**



Hypatia harnesses the flexibility of **Python** to address energy optimization through different modes and embraces **open-source** ethos.

GitHub ANACONDA

1 *Different **Modelling Modes***

Run.py

```
Utopia = Model(
mode="Planning")
# "Planning" or "Operation" mode
```

- ***Planning:*** Minimizing the total discounted costs of the system
- ***Operation:*** Minimizing the total discounted O&M costs of the system

2 *Different **Optimization modes***

Run.py

```
OptimizationMode = "Single"
# "Single" or "Multi" or "MinEm"
```

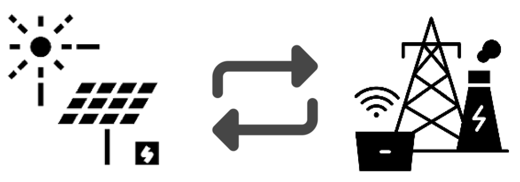
- ***Single:*** Least Net Present Cost optimization
- ***MinEm:*** Least Emission optimization
- ***Multi:*** *Pareto Front* between Least NPC and Least Emissions points

Documentation

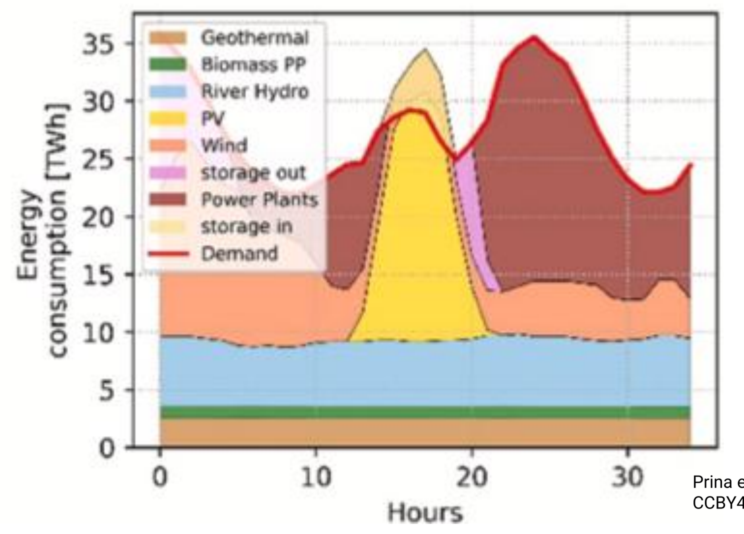
Scan to visit the **online documentation** website of Hypatia with **detailed examples**, main **equations**, **parameters** description and references!

Main Advanced Features

Operation Mode



Hypatia extends the long-term energy planning mode to include **short-term energy planning** and **dispatch optimization** on hourly scale for a year, prioritizing operational considerations over long-term strategies. This functionality enables modelers to prioritize real-time decision-making and efficient resource allocation, crucial for **optimizing energy dispatch** and **grid stability** and energy curtailment in dynamic operating environments. By focusing on short-term operational needs, Hypatia empowers users to address daily fluctuations in demand, integrate renewable energy sources effectively, and enhance overall grid reliability



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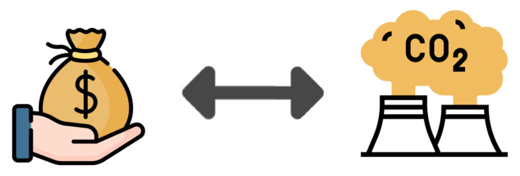
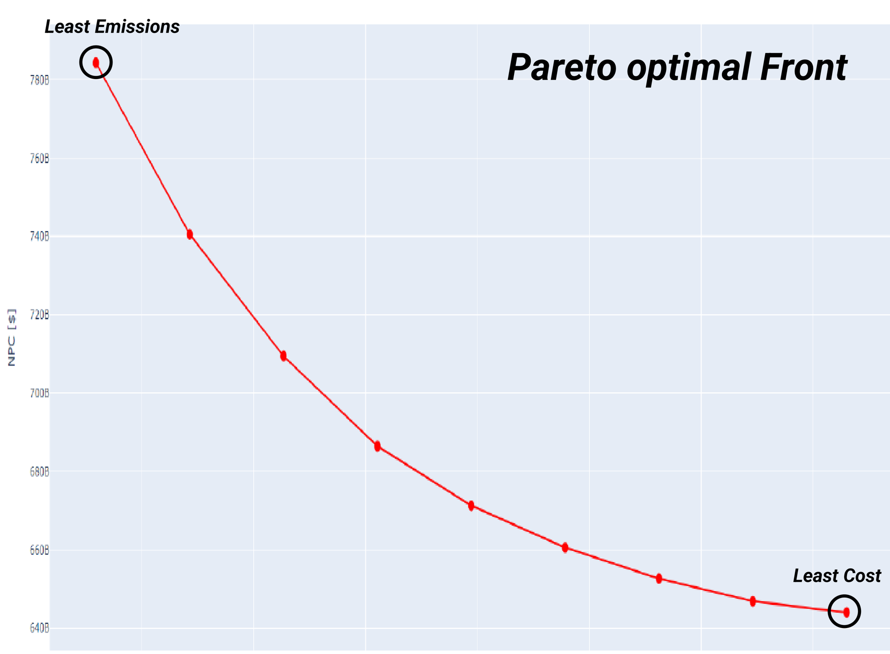
Multi-Objective Optimization



This method employs a **two-stage optimization approach** to **minimize NPC and CO2 emissions.**

The process entails sequential steps to set baselines, determine extremes, and form the **Pareto optimal front**, with Min NPC and Min CO2 representing the extremes of cost and emission minimization. The iterative optimization enables to transform the multi-objective optimization into several single-objective ones.

The Pareto frontiers reveal that initial reductions in CO2 emissions involve minor increases in NPC, while deeper emission cuts lead to significant NPC rises, driven by the adoption of less cost-effective, low-emission technologies.



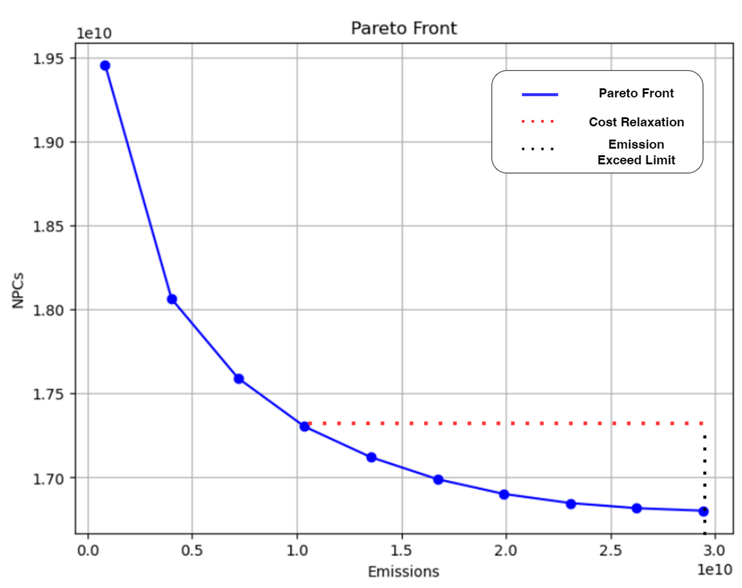
Near-to-optimal Solutions

Modelling for generating Alternative (MGA)

The methodology enables the generation of diverse alternatives by mapping the region between the optimal **Pareto Front** and sub-optimal solutions.

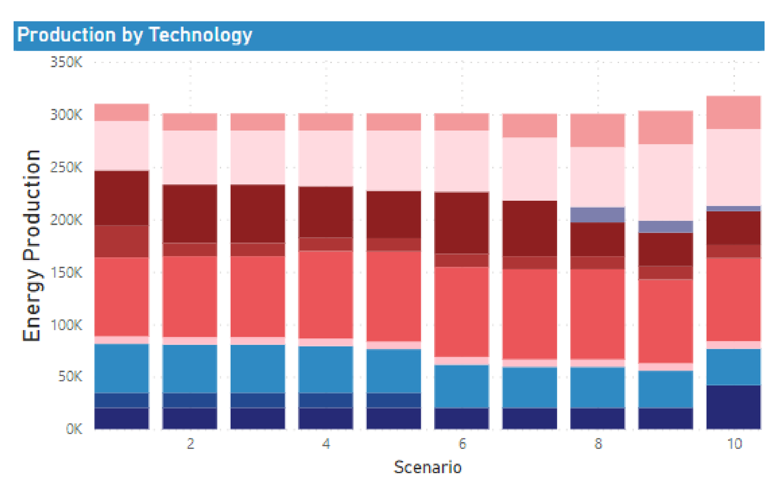
Built through relaxation for the objective function, of which the model has the flexibility to choose different mixes while not exceeding the emissions limits and optimizing the third variable (e.g. land use).

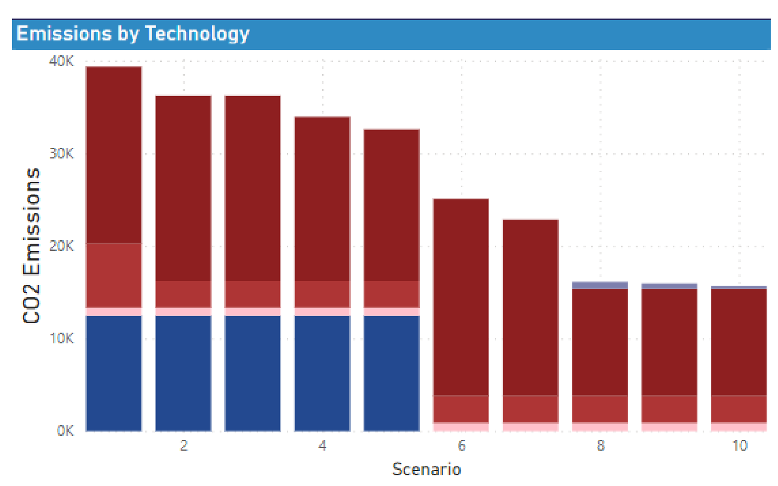
Consequently, MGA identifies **must-have** technologies across scenarios in an energy system, aiding policymakers in selecting energy mixes and investments. Additionally, by considering alternative solutions, the results would provide insights into the feasibility of scenarios, crucial for addressing the multi-faced nexus between energy security, social acceptability and political.



Multi-Scenario Exploration

Multi-Scenario exploration in Hypatia arises from its **diverse modes**, empowering modelers to construct and analyze scenarios comprehensively. This feature facilitates exploration of various solutions, such as integrating *CCUS technologies*, enabling simulation of multiple distinct scenarios for technology adoption. By leveraging the available range specified by the modeler within a single optimization run, Hypatia enables the generation of a spectrum of scenarios, enhancing decision-making and strategy development





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